January, 1995
NSRP 0439

SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1995 Ship Production Symposium

Paper No. 5: Producibility of Double Hull Tankers

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JAN 1995	**N/A**	**-**

4. TITLE AND SUBTITLE	
The National Shipbuilding Research Program, 1995 Ship Production Symposium: Paper No. 5: Producibility of Double Hull Tankers	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230 - Design Integration Tower Bldg 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**28**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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0439

1995 SHIP PRODUCTION SYMPOSIUM

Commercial Competitiveness for Small and Large North American Shipyards

Seattle, Washington
The Westin Hotel
January 25-27,1995

Sponsored by the Ship Production Committee
and Hosted by the Pacific Northwest Section of
The Society of Naval Architects and Marine Engineers
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Jersey City, New Jersey 07306
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0439

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 PAVONIA AVENUE, JERSEY CITY, NJ 07306
Paper presented at the 1995 Ship Production Symposium
Westin Hotel, Seattle, Washington, January 25-27, 1995

Producibility of Double Hull Tankers

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ABSTRACT

Alternative structural system concepts have been developed for 40K and 95KDWT double hull tankers, with the objective of studying their producibility in existing U.S. shipyards, including labor hours and construction schedules. Structural components and elements considered included alternative material, shell plating, bulkheads, stiffeners and other structural elements for both conventional and unidirectional double hull tankers, together with shipbuilding processes such as automation and accuracy control, and standardization including design. It is concluded that increased automation, accuracy control and standardization are the areas where the greatest gains may be possible to make U.S. shipyards more productive and more competitive on a world scale.

INTRODUC'IION

It is generally acknowledged that the labor hours of constructing commercial ships in U.S. shipyards is higher than foreign shipyards, particularly those in the Far East, Southern Europe and BraziI. There are other significant differences of a technical nature which will have a substantial impact, including labor hour requirements for design and construction, materials, equipment and machinery lead time, shipbuilding practices and facilities, use of standards, contractual processes, and institutional constraints.

During the past twenty years, U.S. shipyards, various agencies of the government and the Society of Naval Architects and Marine Engineers (SNAME) have tried to address the matter and improve producibility. U.S. shipyards have acknowledged the advancement of Japanese shipbuilding techniques and,. together with the U.S. Maritime Administration (MARAD), have imported technology from innovators like IHI Marine Technology, Inc. (IHI), who has transferred information to Bath Iron Works Corporation, Newport News Shipbuilding, Ingalls Shipbuilding, Avondale Shipyards, National Steel and Shipbuilding Company (NASSCO) and others. MARAD and later SNAME have sponsored the National Shipbuilding Research Program (NSRP) (now Under SNAME sponsorship with U.S. Navy fundiug), which supports extensive and varied research in shipbuilding technology from design through delivery. However, a significant gap still appears to be present between the U.S. and the major world shipbuilders.

The time required for the construction of a vessel has been identified as having a major impact on vessel labor hours. Reported delivery times in foreign shipyards are considerably less than U.S. shipyards. The reasons for this must be largely tied to the nature of the structure being manufactured and to the degree it facilitates installation of outfit and much of the painting prior to erection on the building berths. The design phase and its integration with construction has a significant influence on achieving this goal. These matters, which are in the shipbuilder's control, are addressed herein.

lt is acknowledged that the world's aging tanker fleet must be replaced in the years to come. This will provide a sigficant opportunity to revitalize shipbuilding in the U.S. Furthermore, the passage of OPA '90 has resulted in new requirements for tankers, specifically double hulls, and this allows significant latitude for the development of designs with innovative enhancements for producibility. These could give the developer a significant advantage over the competition.

The objective of this project was to "develop alternative structural system concepts" for 40,000 (i.e. 40K) and lOOK deadweight tons (KDWT) (reduced to 95KDWT later) Jones Act double hull tankers for construction in existing U.S. shipyard facilities. These should result in decreased labor requirements in the design, instruction, and outfitting phases of the shipbuilding program as well as providing for low cost maintenance during the life of the vessels. It is hoped that addressing this type and these sizes of vessels will provide information to shipbuilders which will be useful in identifying improvements necessary for competing in the upcoming boom for rebuilding the world tanker fleet.

The objective of the project was approached by the plan identified by Daidola [1][1] under contract to the U.S. Coast Guard on behalf of the Ship Structure committee [2].

SHIPYARD FACILITY CONSIDERATIONS

Table I depicts what is considered to be an existing U.S. shipyard, that is, one that would be capable and interested in competing in the world commercial ship market (adopted and modified from [3]). Table II depicts a notional shipyard, which may be considered typical of a modem foreign shipyard.

The study described herein is concerned with existing U.S. shipyards without significant facilities ehancements. Consequently, the data contained in Table II is presented for informational and comparison purposes only.

INSITIUTIONAL CONSTRAINTS

The burden of institutional constraints, in the form of the added cost of compliance with U.S. regulations in the marine industry, has often been cited as a significant contributor to the high cat of building commercial ships in the U.S. This subject was discussed in Reference [4], specifically with regard to the impact of U.S. Coast Guard (USCG) regulations. Some important points extracted from this reference are as follows:

- U.S. shipbuilders have little choice, in many cases, but to purchase marine machinery and equipment from foreign vendors. According to a recent statement by the shipbuilders Council of America (SCA), foreign manufacturers of marine machinery charge premium prices, adding an average of 15% to the material costs of a U.S.-flag ship built in a U.S. shipyard, to cover the costs - real or perceived - of compliance With USCG design and inspection requirements for U.S. flag ships. The cause of this is the erosion of the U.S. supply base for marine equipment and material.
- The American Commission on Shipbuilding, created by Congress through the Merchant Marine Act of 1970 in its "Report of the Commission on American Shipbuilding" cites an addition of 3-5% of the cost of a U.S.-flag vessel for compliance with the technical requirements of the Coast Guard, American Bureau of Shipping (ABS), and U.S. Public Health Service. Other added costs are cited which range horn a low of 1% to a high of 9% of total vessel cost. These differences in cost were largely attributed to implementation of the International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) and its Amendments. The impact of this was particularly severe on the conversion of older ships built before SOLAS 74. However, it should be noted that SOLAS 74, as amended, and Other IMO requirements, have [redacted]minimized the difference between design requirements in force worldwide and those in USCG regulations.
- The cost of ABS classification has been cited as an "add on" cost; however, all commercial ships in foreign trade must be classed by a reputable classification society in order to obtain insurance, and the technical standards and Service charges of the leading Classification Societies are not all that different.
- It is not clear whether all percentages quoted are based on total ship cost or the price the purchaser pays the shipyard for the ship, which may exclude sizeable foreign government subsidies.
- While the percentage figures quoted vary widely, itappears that some small incremental cost of compliance with USCG regulations exists. The USCG is sensitive to this incremental cost and continues to make efforts to reduce the regulatory burden. In any case, a U.S. flag vessel built in a foreign shipyard or withhin the U.S. is required to comply with the same regulations. Therefore, the differences in cost and added time for approval may then be in favor of the vessel building in a U.S. yard.
- USCG regulations are not applicable to foreign flag ships even if built in U.S. yards. The absence, until recently, of foreign flag shipbuilding in the U.S. must be attributed to factors such as long delivery schedules and corresponding high costs at U.S. yards, not any "added" cost of compliance with USCG regulations.

STRUCTURAL ELEMENTS

Structural elements are fundamental features of a structure, such as individual components, type of framing (longitudinal or transverse), flat versus curved plating, incorporation of structural standards, etc., or a production process such as plate forming, flame burning or welding.

Candidate structural elements which can be utilized in assembling alternative structural system concepts having the potential for improving the producibility of double hull tankers have been identified, including components, material, processes, shipyard facilities or design features, as shown in Table III.

[1] Numbers in brackets indicate Reference numbers.

Table I: EXISTING U.S. SHIPYARD

o Mid 1980 technology steel processing and fabrication shops, material handling and cranage. $5 - 10 mil annual improv.

o Facilities
- Plate stockyard
- Shape stockyard
- Plate treatment
- Shape treatment
- Plate processing shop
- Shape processing shop
- Panel line
- Subassembly shop
- Assembly shop
- Shaped assembly shop
- Block platens
- Treatment and coating
- Shop/platens to berth handling
- Berths
- Pipe shop
- Equipment module shop
- Outfitting quay

o Equipment
- Includes plate and shape pre-processing treatment.
- N/C burning machines, plate rolls and presses.
- Line heating, frame bending by hydraulic machine. Panel line for flat stiffened panels. Welding. Subassemblies are processed in designated area and fed to both panel line and shaped structure shop. Pin jigs are used for shape structure. Some multi-wheeled transporters used.
- Equipment and piping produced in outfit package shop.
- Conveyors, overhead cranes in shops, panel and block transporters, outfit pallet trucks, platen cranes and berth cranes are all material handling.

o Designated "On Block" outfitting before or after block coating treatment.
- Deckhouse panels assembled in specialshop for "On Block" outfitting.
- Joiner work done after completion of structure and outfitting.

Table II: NOTIONAL SHIPYARD

o Equipment
- Includes plate and shape pre- processing treatment w/ conveyor handling.
- Line heating, frame bending by hydraulic machine w/ computer templates or inverse lines. Panel line for flat stiffened panels w/ one side welding and automatic stiffener welding. Panels and shaped structure are joined to form 3 dimensional blocks at outside platens.
- Equipment and piping produced in outfit package shop.
- Submerged Plasma cutting/computer controlled.
- Mechanized steel storage handling with remote identification and sensing.
- Cranes with magnetic or pneumatic lift.
- Automatic beam forming.
- Computer fairing, straking, nesting and layout.
- Modular scaffolding.
- Self-traveling staging
- Block or module turning gimbals.
- Hydraulic block alignment systems.

o Complete design, engineering and CAD. Design for production emphasized. Suitable documentation to suit structural block and zone outfitting.

o Welding
- With Fluxcore Wires (FCW welding).
- Welding robotics for the more difficult areas.
- Laser Welding.

o Process lanes.

o Statistical accuracy control.

Table III: STRUCTURAL ELEMENTS

Element

1. Extra wide plating to reduce the number of welded seams.
2. Tapered plating.
3. High percentage of single curvature plate at forward and aft ends.
4. Reduced numbers of piece parts in structural assemblies.

5. Built up plate piece vs. single plate with cut-outs (e.g. lower wing tank web)
6. Corrugated or swedged plating - see Figure 1.
7. Rolled VS. built up Sections.
8. Fabricated stiffeners and girders (possibly of two strength materials) vs. rolled section.
9. Striugers - to facilitate construction and aid inspection.
10. Use of bilge brackets in lieu of longitudinals in the bilge turn area.
11. No longitudinal in bilge turn area and bilge brackets negated due to thicker shell plating.
12. Longitudinal girders without transverses.
13. standardized plate thicknesses in inventoxy. Establish limiting plate thickness to avoid weight gain from transition thickness plate.
14. standardized stiffener sizes in inventory.
15. standardized structurall details (good producibility and weldabiity together with low failure rate).
16. standardized equipment and foundations.
17. Coiled plate. Presumablyy in rolls and would be available in longer lengths.
18. Stiffened elements fashioned from one frame space width of plate with stiffener formed on one side - see Figure 2.
19. Double bottom floors and girders lugged and slotted into bottom shell and inner bottom for easier alignment. Similar technique could be used in wing tanks and on double plate bulkheads etc. - see Figure 3.

Materials

Limit steel grades used to those which do not present problems with welding, fatigue due to less than optimum detailing, etc.

Processes

1. Robotic welding.
2. Robotic painting and paint touch-up.
3. Robotic inspection..
4. Numerically controlled frame cutting.
5. Line heating.
6. Standardized welding details.
7. standardized accuracy..
8. Standardize statistical analysis of structural accuracy variations.
9. Standardized modular/zone construction (interim products).
10. Lapped joints in low stress areas.
11. One sided welds.

Use of Shipyard Facilities

1. Optimize block size to suit shipyard transporter and crane capacities.
2. Optimize sturcture to suit shipyard panel line and other facilities.

Design Features

1. No dead rise, camber or sheer.
2. standardized stiffener spacing.
3. Standardized double skin separation (keep same in all size vessels if feasible).
4. Standardized aft end design - engine room, mooring etc.
5. standardized forward end design - mooring, anchoring etc.
6. standadized transition of double skin to single skin.
7. Formed hopper corner knuckle - see Figure 4.
8. Flat deckhouse sides and ends.
9. Standardize deck heights to minimize number of different heights.
10. standardize size and type Of closures, scuttles, and accesses to the smallest variation practicable.
11. Align and locate all sanitary spaces to simplify piping.
12. Collocate spaces of similar temperature charcterisitcs to minimize insulation requirements.
13. Locate access openings clear of erection joints to allow pre-installation of closures.
14. Provide specific material coating and equipment preferences and reasons for preferences i.e. types of pumps, pump locations, equipmentt makers, cattings, materials, cable types, cable trays, piping arrangements, valve types, valve locations; windlass arangements, hose arrangements, etc..
15. Structurall trunks for cables and pipes (lower tween deck height is then possible).
16. Design risk and possible failure should be considered when proposrng new structural or outfit concepts.

Alternative Structural Concepts

1. Longitudinal framing with formed hopper side comer and corrugated bulkheads.
2. Unidirectional stiffening supporting inner and outer shells, Figure 5.
3. Dished plate unidirectional hull, wherein the added strength due to the curvature in the shell and other plating increases the resistance to deformation and buckling and therefore permits decreased thickness of plating for a given spacing of girders, Figure 6.

Table IV indicates those structural elements applicable to existing shipyards as set forth in Table I. Table V indicates those alternative elements applicable to a notional shipyard as set forth in Table II.

ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS

In order to assemble the structural elements identified into alternative structural system concepts for a double skin tanker, they were first grouped into categories associated with the components of the structural, machinery and outfitting systems, as shown in Table VI.

In order to maintain a manageable number of alternatives and facilitate an objective producibility comparison, some elements and components had to be selectively considered on a subjective basis.

As a result, a series of alternative structural system concepts have been synthesized from the componenets and elements shown in Table VI Each alternative consists of 24 components or elements generically depicted in Table VII. As can be seen, of the 24 components or elements, eleven are directly varied, while the remainder are in accordance with baselines described in Reference [2].

APPLICATION TO SPECIFIC DOUBLE HULL TANKERS

The next step is the application of the alternative structural system concepts to Jones Act double hulI tankers to investigate the potential for improved producibility in the U.S. A further objective is the estimation of baseline construction schedules and labor hours for construction of these vessels.

The sizes of tankers for application in this study were in the 40K to 100KDWT rauge. The Jones Act trade has made use of tankers of approximately 40KDWT over the years, although they have been rarer in the international market with vessels in the 30K+ and 54KDWT sizes being more prevalent. The 100KDWT size range tanker has also been used in the Jones Act Trade. Foreign vessels in this size range are generally just under 100KDWT and of the "Aframax"" type.

As a result, the following procedure was adopted:

- A vessel resembling a 95KDWT 1993-95 vintage Far Eastern built crude carrier was adopted as the baseline vessel. The general arrangement and midship section are shown in Figures 7 and 8 respectively. The principal Characteristics are given in Table VIII.
- A foreign design example for the 40KDWT vessel was not available. Accordingly, a hybrid was prepared utilizing the generic features of the 95KDWT Far Eastern vessel and principal characterstics indicated by previously built 40KDWT tankers for the U.S. Jones Act trade. The general arrangement and midship section are shown in Figures 7 and 9 respectively. The principal characteristics are given in Table VIII.

The unidirectional hulls have slightly different dimensions to suit assumed proportions of the structural cells in the double skin, as shown in Table IX, but cargo capacity is essentially the same as that of the baseline vessel.

BASELINE CONSTRUCTION SCHEDULES AND LABOR HOURS

Typical schedules of construction, distribution of labor hours as well as actual labor hours, were sought in the literature, from shipowner experiences and through foreign - shipyard contacts. Pertinent information was received from all sources on shipbuilding schedules and distribution of labor hours. However, virtually no current information on actual labor hours was obtained, presumably due to its proprietary nature.

Construction schedules have been identified from the sources noted above. Figure 10 shows examples for several types of vessels conatructed in the U.S. and abroad, indicating months from start of fabrication to launch. Fabrication is defined as commencement of steel cutting.

Figure 11 indicates two schedules from contract to delivery for constructing double hull tankers. These schedules are for a Danish yard (84KDWT) [5] and a Japanese yard, [6]. Note that the total schedules from contract signing to delivery are 22 and 20½ months respectively..

Table X shows a 1992 comparison [7] of labor hours and period required for delivery of the first 80KDWT tanker after contract for an average U.S. shipyard and a typical Japanese shipyard. It indicates that the U.S. is superior in outfit and piping construction, but inferior in design techniques, casting techniques and production control. Although the data compares an average U.S. shipyard and a typical Japanese shipyard, no justification is offered for the large differences in the numbers, nor is it clear if the values are applicable to 1992. As shown, the labor hours are 594,000 for the Japanese and 1,374,000 for the U.S. yard. (Note: the reference indicated the U.S. labor hours as 2,374,000, which is believed to be a typographical error.)

Table XI assesses the impact of technologically advanced shipbuilding techniques on labor hour requirements and shipbuilding cycle time, [8]. It is a comparison between an automated and a conventional yard in 1985, and indicates a 32% reduction in labor hours for the automated yard. In addition to labor hour

Table IV: STRUCTURAL ELEMENTS APPLICABLE TO EXISTING U.S. SHIPYARDS

- Rolled vs. built up sections.
- N/C hull penetrations.
- Line heating.
- Maximum block size to suit capability of shipyard facilities.
- Maximum length of blocks to suit steel availability.
- Reduced numbers of piece parts in structural assemblies.
- Rounded gunwale.
- Internal webs of upper wings and hopper from traditional web frames to plate webs.
- Ends of stiffeners for floors simplified for production.
- Cargo area revised to yield identical tanks and therefore identical blocks.
- Cautious approach to use of high strength steels.
- Coating applied environmentally in sheds. 60% done in sheds, 25% on outfitting pier, rest in dock. Blasting w/ steel and 80% re-usable copper grit.
- Pre-installation of access closures.

Table V: STRUCTURAL ELEMENTS APPLICABLE TO A NOTIONAL SHIPYARD

- Standardized accuracy.
- Standardized modular/zone construction (Interim products).
- One sided welds
- Structure optimized for use with builder's process lanes and other facilities.
- Standardized size and type of closures to smallest variation practicable.
- Standardized design details.
- Single curvature longitudinals.
- Developable surfaces.
- Cheaper to change structure to make it more friendly to automation at a fraction of cost of robotics.
- Unidirectional vessel blocks are as long as practical considering crane capacity.
- Engine room block size to 800t.
- Deckhouse 60% outfitting done before lifting on board.
- Deck piping 80% done before lifted on board.
- Standard statistical analysis of structural accuracy variations.
- Robotic welding. (Note - see "cheaper" above)
- Robotic inspection.
- Robotic painting and touch up.

Table VI: COMPONENTS AND ELEMENTS OF STRUCTURAL SYSTEMS

Hull Form
- Flat surfaces
- Developable surfaces
- Compound curvature
- No bulbous bow
- Cylindrical bulbous bow
- Bulbous bow with compound curvature
- Cylindrical bow
- Single screw stern
- Single screw stern with bulb
- Twin screw stern

Deckhouse
- Block configuration
- Straight sides and ends
- Flat decks

Tank Arrangement (in addition to double skin)
- No CL or wing bulkheads
- CL bulkhead (oil tight or non tight)
- Wing bulkhead P/S

Machinery
- Single screw slow speed diesel
- Single or twin screw medium speed diesels

Pumping System
- Variable

Rudder
- Horn type
- Spade type

Shell
- Smooth plate
- Dished plate

Shell and Deck Longitudinals
- None
- Flat bars
- Angles
- Tees
- Bulb flats
- Rolled vs fabricated sections
- Unidirectional system

Deck
- No sheer
- No camber
- Parabolic camber
- Straight line camber with C.L. knuckle
- Straight line camber with knuckle P/S
- Single vs double skin

Main Bulkheads
- Stiffened Plate
- Corrugated
- Double Plste

Girders
- Stiffened plate
- Swedged plate

Plate
- Fist
- Swedged
- Corrugated
- Dished

Inner Hull Connection to Inner Bottom
- Bracketed
- Sloped hopper
- Sloped hopper with formed comers
- Radiused caner (unidirectional designs)

Main Deck/Sheer Strake Connection
- Square (sheer stroke extends above deck)
- Radiused

Blocks
- Number of blocks
- Size and weight
- Structural complexity
- Number of pieces
- Shoring, pins or jigs
- Number of turns

Material
- Mild Steel (MS)
- High strength steel (HSS)
- Combination (HSS/MS)

welding
- Manual
- Automatic
- Robotic

Plate Forming
- Rolling
- Pressing
- Line Heating

Accuracy
- Normal Standard
- High standard

Shipyard Facilities
- cranes
- Transportation
- Automation
- Material throughput
- Process lanes

structural Details
- Stsndard
- Specialized/Fitted

coatings
- Pre-construction primer
- standard quality
- High quality

Design
- Standardization

Maintaiability, Strength and Fatigue
- Accessibility
- Smooth surfaces
- structural intersection.

Table VII: GENERIC ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS

Component or Element	Characteristics	Component or Element	Characteristics
1. Hull Form	Baseline	14. Main Deck/Sheer Strake (Gunwale) Connection	Baseline
2. Deckhouse	Baseline	15. Blocks	Baseline
3. Tank Arrangement	Per Alternative	16. Material	Per Alternative
4. Machinery	Bsseline	17. Welding	Per Alternative
5. Pumping System	Baseline	18. Plate Forming	Per Alternative
6. Rudder	Baseline	19. Accuracy	Baseline
7. Shell	Per Alternative	20. Shipyard Facilities	Baseline
8. Shell and Deck Longitudinals	Per Alternative	21. Structural Details	Per Alternative
9. Deck	Baseline	22. Coating	Baseline
10. Main in Bulkheads	Per Alternative	23. Design (Standardization)	Per Alternative
11. Girders	Baseline	24. Maintainability, Strength and Fatigue	Baseline
12. Plate	Per Alternative		
13. Inner Hull Connection to Inner Bottom	Per Alternative		

Table VIII. BASELINE DOUBLE HULL TANKER PRINCIPAL CHARACTERISTICS

	40KDWT	95KDWT
Length B.P. (LBO)	183.00M	234.00M
Breadth B	31.00M	41.50M
Depth D	17.70M	19.75M
Design draft	11.28M	13.75M
Block Coefficient C_b	0.80	0.83
SHP	8,500	13,000
Displacement	52,790MT	114,280MT
Lightship	12,790MT	19,280MT
Wing Tank Width	2.20M	2.70M
Double Bottom Width	2.20M	2.20M
Cargo Tanks	7 @ 17.90M	7 @ 25.06M

Table IX: UNIDIRECTIONAL DOUBLE HULL ALTERNATIVES

95 KDWT	U1	U2	(Dished Plate)
Breadth B	40.75M	41.8 M	40.4M
Depth D	21.0 M	22.4 M	21.2M
Wing Tank Width	2.0 M	2.2 M	2.2M
Double Bottom Depth	2.6 M	2.2 M	2.2M
Bottom Girder Spacing	1.75M	1.15M	2.4M
Side Grider Spacing	1.45M	1.15M	2.4M
Deck Void Depth	1.0 M	2.2 M	2.2M

40 KDWT	U4	U5	(Dished Plate)
Breadth B	30.5 M	30.85M	30.8M
Depth D	17.57M	19.35M	18.8M
Wing Tank Width	2.0 M	2.2 M	2.2M
Double Bottom Depth	2.6 M	2.2 M	2.2M
Bottom Girder Spacing	1.75M	1.15M	2.4M
Side Girder Spacing	1.45M	1.15M	2.4M
Deck Void Depth	1.0 M	2.2 M(open to cargo)	2.2M

Table X COMPARISON OF PRODUCTIVITY (Baseline of 1.0 for Japan, unless otherwise specified) (1992), PI.

Item	U.S.*	Japan
ships	Construction of five 80,000 dwt class tankers.	
Area of plant	2.5	1.0
Travel distance of materials	5.0	1.0
Number of built-up blocks	209	250
Period required for delivery of the first ship (after contract)	140 Weeks (2.33)	60 weeks (1.0)
Labor hours for first ship	1,374,000 (2.31)	594,000 (1.0)

* U.S. superior points: outfit, piping construction. source: U.S. Maritime Adminstration
U.S. inferior points: designing techniques, casting techniques, production control.

Table XII provides data for five single hull vessels built and delivered at IHI Yokohama Shipyard in the year 1972, [6]:

Table XI: LABOR ALLOCATION (High-class cargo ship) (1985), [8].

	Labor % Automated Yard	Labor % Conventional Yard
Steel fabrication	3	4
Panel and shell	4	6
outfitting:		
Electrical	4	4
Pipe	2	3
Machinery	4	5
Other	5	5
Subassembly	22	11
Block assembly	31	-
Ship erection	14	30
Launch	1	1
Post-launch outfit	10	31
	100%	100%
Total labor hours	68%	100%
Time rquired	54%	100%

Table XII: DATA ON SINGLE HULL SHIPS BUILT AT IHI in 1972, [6]

Type	Size
OBO	224,070 dwt
Tanker	230,906 dwt
Tanker	227,778 dwt
Tanker	219,803 dwt
Tanker	232,315 dwt

savings, this effects a higher facility utilization (more throughput), resulting in higher return on investment capital. For this comparison, an automated yard is one in which investments have been made into increasing automation, i.e. automatic beam forming, cranes with pneumatic or magnetic lift, self traveling staging, welding, robots, etc.

The beneficial impact of statistical accuracy control on labor hours has been discussed in various references, [9] through [14]. These studies indicate that potential improvements of 15% or more are attainably by the employment of this technique, which result in the virtual elimination of unnecessary fitting and rework. Such improvements have already been achieved in some Far Eastern yards.

Table XII provides data for five single hull vessels built and delivered at IHI Yokohama Shipyard in the year 1972, [6].

The new construction of Table XII was achieved with one building dock, supported by two 120-ton cranes and one 30-ton crane, [15]. The area of the yard used for such construction was just over 50 acres. From details of the labor force provided in [6], it may be deduced that an average of 988,000 labor hours per vessel, excluding design hours, was required for construction.

Recent labor hour distribution data for construction of 40 and 95 KDWT double hull tankers in Japan was obtained from [6] and data for construction of an 84KDWT double hull tanker in Denmark was obtained from [5]. This data is summarized in Table XIII below. Tables XIV and XV give the steel and outfitting breakdowns of Table XIII.

To produce the Table XIV breakdown of steel labor hours, the original categories received from the Danish shipyard (steel processing, sub-assembly, flat and curved panels, blocks, erection, transport and riggers) were re-combined to better compare with those of the Japanese shipyard so that a meaningful comparison of labor hours could be made. Note that the Danish coating of cargo and water ballast tanks were subcontracted. It can be seen that if this item is added into the Danish total, then their outfitting percentage would increase and their steel percentage would decrease, possibly coming into closer agreement with the Japanese values.

If it is assummed from Table XIII that an average of 59% steel and 41% outfit breakdown in labor hours was consistent with Japanese production in 1972, then the 988,000 labor hours derived from Table XII for single hull tanker construction in Japan would divide into 582,000 labor hours for steel and 405,100 labor hours for machinery/outfitting. Some support for assuming identical distribution of labor hours in 1972 and 1994 can be gleaned from a consideration of the advances made in shipyard steel fabrication through automation, and at the same time the modular nature of some of the outfit delivered to a shipyard together with pre-outfitting. The above data can then be used to estimate the labor hours required in Japan in 1972 to construct 40K, 95K and 84K double hull tankers, and then to project the estimates to 1994.

For this propose, it has been assumed that the total steel labor hours vary in some manner with the total weld length required for construction. To determine the relationship between weld length and vessel dimensions, a flat plate structural unit with longitudinals and transverse webs was first considered. As shown in [2], the total length of welds for the complete unit varies with the area of the flat plate panel.

To extend this reasoning to a ship, it may therefore be assumed that the total length of welds (and therefore the steal labor hours) in similar ships, with similar construction and block coefficients, varies approximately with an area numeral such as L (B+D). For a better account of welding on main transverse bulkheads, a factor xBD may be added, where x is the number of bulkheads. For comparing ships with different internal arrangements however, such as single hull and double hull tankers, the numeral must be modified to take account of the inner bottom, the side tanks and any additional longitudinal bulkheads. Thus, for a single hull tanker with two longitudinal bulkheads and say ten transverse bulkheads, the numeral becomes Ns= (2LB + 4LD + 10BD). For a double hull tanker with a center-line longitudinal bulkhead and ten transverse bulkheads, the numeral becomes ND = (3LB + 5LD + 10BD).

The average Japanese tanker deadweight in Table XII was taken to be 228,000 tons (single hull) and estimated dimensions of the vessel were derived. The dimension of the 84KDWT Danish double hull tanker were obtained from [5], while the dimensions of the 40K and 95KDWT double hull tankers are those given herein for the baseline vessels.

Table XVI was then prepared, providing a comparison of labor hours for the construction of tankers in Japan in 1972. The labor hours for construction of the 228KDWT single hull tanker were derived previously by assuming steel labor hours and machinery/outfitting labor hours to be 59% and 41% of the total hours respectively. The steel labor hours for the 40K, 95K and 84KDWT double hull tankers were then obtained from those of the 228KDWT tankers by **application of the factors N_D/N_S. The resulting hours** were then taken to be 59% of the total, with the remaining 41% applying to machinery/outfitting. Total labor hours were increased by 50,000 for design, as surmised from [16], although this figure appears to be quite optimistic.

To estimate the increase in productivity in Japan by 1994 half of the improvement introducibility indicated in Table XI for automation (i.e. 16%) and half of the improvement previously discussed for statistical accuracy control (i.e. 7.5%) were taken as having occured by 1972, as significant strides had been made in the construction of large tankers by then. The labor hours for construction in Japan in 1994 can then be derived from those in Table XVI (excluding design hours) by applying similar percentage improvements from 1972 to 1994, i.e. by multiplying by 0.84x0.925 = 0.777.

Using the 1994 values of steel and machinery/outfitting labor hours derived in this manner, a comparison can be made using both the Japanese and Danish labor hour breakdown percentage of Tables XIII through XV to construct Tables through XIX. These Tables represent am estimate of the labor hour distribution for the 40K and 95KDWT base alternatives and an 84KDWT tanker, using 1994 estimates of total labor hours. It should be noted that the total hours for the 84KDWT data are based on the Japanese data, but its labor hour distribution is based on the Danish data. The latter distribution has been included for purposes of comparison. It may be noted that the total labor hours for the 84KDWT vessel compare favorably with those for an 80KDWT tanker given in Table X, although it is not known whether the latter vessel was a single or double hull tanker.

According to information recently received, [17], the following labor hours for construction were achieved by Japanese and Korean shipyards in 1992:

	Japan	Korea
280KDWT single hult tanker	380450,000	700-S00,000
280KDWT double hult tanker	S50-650,000	850-950,000
150KDWT single hull tanker	About 300,000	About 640,000

This information indicates that the projected Far East labor hours for 40K and 95KDWT double hull tankers given in Table XVIII are supported by the Korean data.

Reference [18] states that some medium and smaller Japanese shipyards are building double hull Aframax tankers (approx. 95KDWT) for 200,000 hours. These hours and the japanese labor hours above

Table XIII: STEEL AND OUTFITTING RELATIVE LABOR HOURS FOR DOUBLE HULL TANKERs

	Jspanese*	Danish**
steel	55-63%	70%
outfitting	45-37%	30%

*IHI **B&W

Table XIV: STEEL LABOR BREAKDOWN FOR DOUBLE HULL TANKERS

	Japanese 40KDWT	Japanese 95KDWT	Danish 84KDWT
Parts Cutting & Bending	15%	14%	13.75%
Sub-assembly	13%	13%	12.75%
Assembly	45%	48%	45.25%
Erection	27%	25%	28.25%
Steel Total	100%	100%	100%

TABLE XV: MACHINERY/OUTFITTING LABOR BREAKDOWN FOR DOUBLE HULL TANKERS

	Jspsnese 40KDWT	Jspanese 95KDWT	Danish 84KDWT
Machine Shop			2%
Pipe fab. and machinery pkgs.	11%*	lo%*	10%
Pipe installation			21%
Misc. steel outfitting			17%
Hull & Accommodation	25%*	23%*	
Mechanical Installation			8%*
Joiners & carpenters			8%*
Machinery Outfitting	18%	16%	
Electrical Outfitting	9%	9%	16%
Tests & trials incl. Dry Dockg.	6%	8%	
Painting	31%	34%	18% Danish coating of cargo -----& WE tanks subcontracted
outfitting totals	100%	100%	100%

*Affected by hull structural concept

Table XVI: ESTIMATED LABOR HOURS JAPAN 1972
(All vessels double hull except 228KDWT)

DWT (M.T.)	LxBxD (meters)	N_S or N_D	N_D/N_S	Steel Hours (59%)	Machy/Outfit Hours (41%)	Total * Labor Hours
228K	313x51x26.18	N_S=78055	-	582,920	405,080	1,038,000
40K	183x31x17.7	N_D=38702	0.50	291,460	202,540	544,000
95K	234x41.5x19.75	N_D=60437	0.77	448,848	311,911	810,759
84K	229x32.24x21.6	N_D=53845	0.69	402,215	279,505	731,720

* Includes 50,000 hours for design [1

Table XVII: ESTIMATED STEEL LABOR HOURS (Japan 1994)

	40KDWT	95KDWT	84KDWT
Parts Cutting & Bending	33,970	48,826	52,972
Sub Assembly	29,440	45,338	39,846
Assembly	101,909	167,402	141,416
Erection	61,145	87,189	88,287
SteeI Total	226,464	348,755	312,521

Table XIII: ESTIMATED MACHINERY AND OUTFITTING LABOR HOURS (JAPAN 1994)

	40KDWT	95KDWT	84KDWT
Machine Shop			4,343
Pipe Fab. & Mach. Packages	17,311*	24,235*	21,717*
Pipe Installation			45,607*
Misc. steel Outfitting			36,920*
Hull & Accommodations	39,344*	55,742*	
Mech. Installation			17,374*
Joiners & Carpenters			17,374*
Machinery Outfitting	28,327	38,777	
Electrical outfitting	14,M4	21,812	34,748
Tests & Trials inc. Dry Docking	9,442	19,388	
Painting	48,786	82,401	39,092 (Danish coating of Cargo and WB tanks subcontracted
Machinery & Outfitting Total	157,374	242,355	217,175

*Affected by uniqueness of hull structural concept and difference from base vessel.

Table XIX: TOTAL STEEL, MACHINERY & OUTFITTING (Japan 1994)

Total Steel & Machinery Outfitting	383,838	591,110	529,696

are so low compared with historical and other data bases that for the purposes of this study the Korean hours have been taken to be typical of Far East construction.

Figure 12 provides the Danish B&W yard’s "Learning Curve" for series production of 17 double hull tankers of 84KDWT, [51]. The production index of that figure shows that after production of the 17 vessels, the index dropped from 100 down to nearly 50. Stated another way, a shipyard building such a series design can construct the last vessel in one half the labor hours of a shipyard with a one-off design. This displays a clear case for series production and its effect on producibility which, on face value, is likely to overshadow any other improvements on producibility.

However, the advantage of series production is available to all shipyards. A learning curve is not a fixed line and can be improved (i.e. displaced downwards) by superior work methods or design changes. A shipyard that can improve a learning curve by constant samll downward displacements will be more competitive.

APPLICATION OF ALTERNATIVE STRUCTURAL SYSTEMS

From the list of generic alternative structural system concepts given in Table VII, a series of alternative concepts was identified for study and evaluation for both the 40K and 95KDWT vessels.

For the identification of the various structural alternatives, a key code was established as follows. The key number for each 40KDWT alternative starts with 40 and ends in a number such as 10, assigned to identify the structural configuration of the alternative. For example, the 40KDWT base alternative has the number 4010 assigned to it. The other 40K alternatives have numbers 4020, 4030 etc. assigned to them. Similar key numbers, such as 9510, 9520 etc. have been assigned to the 95KDWT alternatives. A full list of the alternatives investigated, together with their key numbers, is provided in Table XX. These numbers appear on all calculation sheets. Alternatives 9590 through 95112, 95130, 95140 and 95150 were not evaluated since experience with other alternatives indicated that the relationship of their producibility to the remainder of the 95KDWT series would not differ greatly from the relationship exhibited by the 40KDWT series.

A midship section was synthesized for each structural system concept considered. The midship scantlings for all longitudinal items were obtained from the American Bureau of Shipping (AIM) program OMSEC, Which incorporates all pertinent sections Of ABS Rules.

It should be noted that stiffener sizes were selected from a limited range of flat bars and built-up shapes included in the program which can result in some stiffeners being oversized. This procedure was followed since it is the practice in some shipyards to restrict stiffener sizes to a limited range to simplify storage, handling and design details. However, intermediate sizes of stiffeners were also added to the program and alternatives 4030 and 9530 included in the list of structural alternatives studied, so that any oversized stiffeners could be replaced by smaller sizes. Alternatives 4030 and 9530 are otherwise similar to the base alternatives 4010 and 9510 respetively. Since they are not included in the OMSEC program, the scantlings of transverse structure and bulkheads were determined from ABS Rules for the 40KDWT and were adapted from similar ship's drawings for the 95KDWT alternatives.

For the unidirectional alternatives, an assumed spacing of longitudinal girders was used to enable the OMSEC program to calculate the required minimum ABS Rule shell plating thickness. In addition, some approximate calculations were **performed to** obtain representative scantlings for the longitudinal girders.

For the dished plate unidirectional alternatives, plating thickness was estimated by considering the additional strength due to curvature over an equivalent flat plate structure. It should be noted that the spacing of longitudinal girders for the dished plate vessels is greater than that of the other unidirectional alternatives, as approximately identical shell thickness was maintained and the additional strength due to curvature allowed greater girder spacing. Also, the scantling of the dished plate double hull were maintained constant around the entire periphery of the midship section. This feature, which can be applied to any of the unidirectionall alternatives, enables the number of unique structurall blocks to be considerably reduced, but incurs some weight penalty.

To simplify the producibility investigation, yet keep it meaningful, only one midship cargo tank length of each structural alternative concept, including one transverse bulkhead, was selected for initial comparison and evaluation.

Since the producibility study required seams and butts of plating to be located, it was then necessary to break down the midship tank structure into suitable blocks for erection, as shown in Figure 13 for the 40KDWT vessels. The breakdown for the 95DKWT vessels is similar.

The lengths of the blocks were based on the length of cargo tanks (17.9m. for 40K and 25.06m. for 95KDWT alternatives) and the 3.58m. spacing of transverse floors and webs. Thus, the block lengths are 7.16m. forward and 10.74m. aft for 40K and 10.74m. forward and 14.32m. aft for 95KDWT alternatives. These arrangements provide some repetitive blocks within the parallel mid-body of the vessels. me transverse bulkheads inside the double hull formed separate blocks.

ESTIMATES OF PHYSICAL PRODUCTION CHARACTERISTICS

In considering the producibility of the various alternative structural system concepts, it is necessary to consider many characteristic aspects of the structure, including the following, [20]:

- amount of welding
- type and number of frames, and stiffeners
- number of unique pieces
- total number of pieces
- weight
- surface area for coatings
- number, type and position of welded joints

Table XX: ALTERNATIVE STRUCTURAL SYSTEM CONCEPTS

NOTE All vessels 4010 through 4090 and 9510 through 9580 have high strength steel (grade AH32) in the deck and bottom except 4020 and 9520. All unidirectional vessels are mild steel except 40112, which has high strength steel in the deck and bottom. All vessels have conventionally stiffened transverse bulkheads (vertical stiffeners) and center line bulkheads (longitudinal stiffeners), except where noted otherwise.

Key №.

4010- 40KDWT base vessel with square (bracketed) lower outboard corner of cargo tank.
9510- 95KDWT base vessel with sloped tank side (hopper] at lower outboard comer.
4020- Same as 10, except all mild steel.
9520- Same as 10, except all mild steel.
4030- Same as 10, three times the stiffener sizes in order to minimize weight.
9530- Same as 10, with additional stiffener sizes, as in 4030.
4040- Same as 10, with vertically corrugated transverse bulkhead.
9540- Same as 10, with vertically corrugated transverse bulkhead.
4050- Same as 60, but sloped hopper fitted with formed corners.

9550 - Same as 10, but sloped hopper fitted with formed corners.
4060- Same as 10, but with sloped hopper at lower outboard corner.
9560- Same as 10, but with square (bracketed) lower outboard comer of tank.
4070- Same as 10, but with bulb plates in lieu of other stiffeners.
9570- Same as 10, but with bulb plates in lieu of other stiffeners.
4380- Same as 10, but with stiffened elements fashioned from one frame space width of plate with stiffener formed on one side. This in lieu of plate stiffener combinations.
9580- Same as 10, but with stiffened elements fashioned from one frame space width of plate with stiffener formed on one side. This in lieu of plate stiffener combinations.
4090- Same as 10, but with all floor, girder and web stiffeners assumed automatically welded.
40100- U4 - Unidirectional alternative with vertically corrugated transverse and center line bulkheads.
40110- U5 - Unidirectional alternative with vertically corrugated transverse and center line bulkheads.
40111- U5 - Unidirectional alternative with double plate transverse bulkhead and vertically corrugated center line bulkhead.
40112- U5 - Unidirectional alternative with high strength steel deck and bottom, vertically corrugated transverse bulkhead and no center line bulkhead.
40120- U6 - Dished plate unidirectional alternative, with vertically corrugated transverse and center line bulkheads. Dished plating formed by rolling.
95120- U3 - Dished plate unidirectional alternative, with vertically corrugated transverse and center line bulkheads. Dished plating formed by rolling.
40121- U6 - Dished plate unidirectional alternative - same as 120, but dished plating formed by pressing and credit given for unique welding. Also, floor, girder and web stiffeners assumed automatically welded.
95121- U3 - Dished plate unidirectional alternative - same as 120, but dished plating formed by pressing and credit given for unique welding. Also, floor, girder and web stiffeners assumed automatically welded.
40130- Same as 10, but double bottom floors and girders lugged and slotted into bottom shell and inner bottom for easier alignment.
40140- Same as 10, but 50% labor hour reduction for series production of standard vessels.
40150- Same as 10, with use of design standards for contract/detail designs. Design labor hours reduced from 200,000 to 100,000 and schedule reduced to suit.

- self-alignment and support
- need for jigs and fixtures
- work position
- number of physical turns/moves before completion
- aids in dimensional control
- space access and staging

- standardization
- number of compartments to be entered to complete work

The quantification of these characteristics for producibility considerations should generally be in terms of physical quantities, i.e. weight, number of pieces, number and length of welded joints, etc., or the labor hours and schedule time required for their construction or application. The remainder of this sub-section describes how the physical quantifications were made.

The structure of one complete midship tank section for each alternative, port to starboard, including one transverse bulkhead, was studied for the purposes of considering producibility. Following the breakdown into structural blocks, the quantification of the characteristics noted above then required each one tank length alternative to be broken down into all its component plates, longitudinals, stiffeners, brackets and chocks. A spreadsheet computer program was utilized for this purpose to form the basis for quantifying the various physical steel construction properties of the alternatives, including the number of unique pieces, total number of pieces, dimensions and thickness of plates, type, length, thickness and cross section area of longitudinal and stiffeners, surface areas of plates, longitudinals and stiffeners, weights, weld type (automatic, manual, fillet, butt), weld position and weld length. These properties of the various alternatives were derived for each structural block and then totalled for all blocks. Metric units were used throughout.

Manual and automatic welding processes were considered for both fillet and butt welds. Longitudinal erection seams were assumed to be automatically welded, while transverse erection butts were assumed to be manually welded. Elsewhere, manual or automatic welding was assigned. Plate thicknesses were subdivided for welding purposes according to whether they were less than/equal to 19 mm or greater than 19mm, since the latter require significantly more edge preparation than lesser thicknesses, such as 10 to 16 mm., [21]. Weld length for plates was split up into flat and curved plate categories. Weld positions considered were flat (i.e. downhand), horizontal (on sloping or vertical structure), vertical and overhead.

The welding of the hull structure of the unidirectional alternatives was assumed to be conventional, i.e. longitudinal plate seams butt welded clear of longitudinal girders, which are fillet welded to the shell plating etc. However, for the dished plate unidirectional alternatives, it is understood that a highly automated welding process is being developed for the welding of the longitudinal girders to the shell plating etc., [22] [23]. As shown in Figure 6, the junction of a longitudinal girder with adjacent panels of dished plating forms a 3 way joint. Since it is believed that this joint is welded completely by the above process, it would appear that the welding must be performed with the joint set vertically. Robotic welding of the girder stiffeners has also been proposed.

For estimating steel labor hours for the dished plate unidirectional alternatives 40120 and 95120, welding of the 3 way joints was assumed to be equivalent to automatic vertical butt welding, with manual welding of the girder stiffeners. However, in anticipation that the special welding technique referred to may be transportable in some form to an existing U.S. yard without existing facilities enhancements, dished plate Unidirectional alternatives 40121 and 95121 Were considered to be welded with this technique, to represent the application of such technology. The labor hours for the vertical 3 way joints were then taken identical to those for the fastest conventional welding, i.e. automatic downhand welding. Automatic welding of the girder stiffeners was also made, so as to mimic the proposed robotic welding. It should be noted that the 3-way joints could also appear in the smooth plate unidirectional alternatives, and their application in 40121 and 95121 should be indicative of the benefit in both types of alternatives.

LABOR HOURS AND SCHEDULES

Approach

As indicated earlier, it was decided to estimate steel labor hours by adopting and modifying a method proposed in References [24] and [25].

U.S. shipbuilding's introduction of automation and accuracy control has been advancing but is acknowledged as being behind that abroad [8]. As a result, they were taken as one half of the 32% presented in Table XI for a Far Eastern automated yard's advantage over a traditional yard in 1985 and one half of the 15% improvement in overall production by implementation of strict dimensional controls and statistical accuracy, as discussed earlier for Far Eastern yards. Then, U.S. yards can be expected to achieve the labor hours and schedules of construction for the base alternative vessels shown in Table XXI and XXII respectivley. The schedules in Table XXII, also shown in Figure 14, are from contract signing to delivery, and have been developed to incorporate about 12 months from the start of fabrication to launch, since this was required in 1983 for the last series of tankers to be constructed in the U.S. - see Figure 10. These schedules have some potential slack at the beginning and end (particularly from trials to delivery), allowing for meeting contractual dates. It may be noted that the design labor hours were based on the anticipated performance of U.S. shipyards. It may be further noted that according to the data provided by Reference [6], there is almost no difference between the 40K and 95KDWT Far East baseline building schedules. Therefore no difference is shown in Table XXII.

Labor Hours For Steelwork

The following **notes** provide the assumptions, approaches and details of the method used to estimate the steel labor hours required for the construction of the various one tank length alternatives.

a) In order to estimate the steel labor hours required to construct one midship cargo tank section for the various structural alternatives, the steel labor hours required to construct the complete 40K and 95KDWT base vessels were first obtained from the total labor hours (excluding design labor) given in Table XXL For this purpose, the average percentage breakdown of steel versus outfitting hours given in Table XIII for the construction of vessels in Japan was used, i.e. 59% for steel construction and 41% for outfitting. Then total steel labor hours to construct 40K and 95KDWT base vessels are 291,460 and 448,848 respectively.

An estimate of the steel labor hours to construct one cargo tank section for the base vessels was then obtained from a consideration of the relative lengths of the separate parts of the vessels (i.e. 7 cargo tanks + bow + stern + Superstructure), the structural contents of each part and the relative complexity (e.g. curved shell plating) of the structure. Approximately 10% of the total steel hours are required.

b) In order to study the various structural one tank length alternatives, a method of estimating the steel labor hours for each, as compared with the two base designs, was now required. It was therefore decided to utilize the method provided in References [24] and [25] to obtain the labor hours to construct the various one tank length alternatives.

c) For the application of this procedure to the structural alternatives, surface preparation, coating and testing were removed from the list of work processes utilized for estimating purposes, since they were considered to be part of machinery/outfitting for the purposes of this study. However, "rework" was included as an additional factor.

Labor Hours For Construction Of Complete Vessels

As previously indicated, the steel labor hours for the construction of the midships one tank length alternatives were estimated to be approximately 1/10 of the total steel labor hours for the 40K and 95KDWT designs respectively. However, to allow for the transition of cargo tank structure into the bow and stem portions of the vessels, it was decided to maintain the **steel labor hours for the construction of №1 cargo tank** section, the bow and the stem constant for the two sets of vessel sizes and equal to the hours determined for the 40K and 95KDWT base alternatives in these areas. The steel labor hours for the deckhouses were similarly held constant. This resulted in a constant portion of the steel labor hours for the 40KDWT alternatives of 134,300 hours and for the 95KDWT alternative 160,150 hours.

The machinery/outfitting labor hours required to construct the complete 40K and 95KDWT base vessels were taken to be 41% of the total labor hours (excluding design labor) given in Table XX.

Table XV gives a percentage breakdown of the labor hours required for machinery/ outfitting, and indicates that the labor hours required by the Japanese for painting were 31% of the total machinery/outfitting hours for 40KDWT vessels and 34% for 95 KDWT vessels. These percentages were applied to the two base vessels, and for the remaining alternatives, the labor hours for painting were varied in proportion to the surface area of the steel components.

Design labor hours for the 40K and 95KDWT alternatives were estimated at 200,000 and 225,000 hours respectively, except for alternative 40150 providing for enhanced standardization where significant detail design data or working drawings are on file, for which they were reduced to 100,OOO.

The total labor hours for the various alternatives were then obtained by summing up the hours for steel construction, the constant hours for machinery/outfitting, the hours for painting and the hours for design. For the baseline vessels, the resulting total labor hours for the construction of the 40K and 95KDWT alternatives in the U.S. in 1994 were 712,800 and 958,100 respectively. The results of all calculations are shown graphically in Figures 15 and 16 respecdvely.

Construction Schedules

Figure 14 and Table XXII provide the estimated construction schedules in a U.S. shipyard for the 40K and 95KDWT baseline vessels. These schedules are a modified version of those provided by Reference [6] for similar vessels building in the Far East. This reference shows almost no difference in schedules for the **40K** or 95KDWT vessels, and this is reflected in Table XXII. T'he Far East schedule was modified to reflect predicted U.S. attainment in 1994 as follows:

Table XXI: TOTAL ESTIMATED LABOR HOURS FOR CONSTRUCTION OF BASELINE SHIPS IN U.S. IN 1994

	40KDWT	95KDWT
Far East Base Labor Hours for construction (from Table XIX)	383,838	591,110
Increase for U.S. due to lesser automation and accuracy control.	110,162	169,649
Design Labor	200,000	225,000
U.S. Total Labor Hours	694,000	985,759

Table XXII: ESTIMATED SCHEDULE FOR CONSTRUCTION OF BASELINE SHIPS IN U.S. IN 1994

	40KDWT	95KDWT
Far East Baseline Schedule, including design (from Figure 11)	20.5 months	20.5 months
Increase for U.S. due to lesser automation and accuracy control, applied from fabrication to sea trials.	2.6 "	2.6 "
Additional Design Period	6.0 "	6.0 "
U.S. Schedule for Construction	**29.1** months	29.1 months

- The design time was increased from 8 months to approximately 14 months (6 months increase) to provide additional design time for one-off ships with less incorporation of standard interim products..
- It is assumed that the time line between the commencement of steel fabrication and sea trials increase by 2.6 months to allow for the lesser utilization of automation and accuracy control U.S. shipyards.
- The time line between commencement of steel fabrication and launching was increased from 7.4 to 12.4 months, to suit the U.S. construction data for 40KDWT tankers in Figure 10. This 5 month increase was overlapped into the design period.
- The time line between sea trials and delivery (3.5 months) was unchanged assuming the same yard would produce all alternatives with a 3.5 in month sea trial to delivery time.

Thus, the U.S. baseline schedule was increased to 29.1 months, and this was used as a basis for the estimation of schedules for the various structural alternatives. Key milestones such as the commencement of fabrication, keel laying and launching are included in Figure 14, which also incorporates time lines for assembly, erection and painting. The time spread of these time lines and the locations of the key milestones given in the Far East schedule were modified to suit the above changes. It should be noted that in preparing the basic schedule for construction in U.S. shipyards, it has been assumed that all required material and equipment would be delivered to the shipyard as required to meet the schedule. Any delay in such deliveries would impact on the schedule and increase vessel costs.

For estimating the construction schedules for the various 40K and 95KDWT alternatives, the pertinent information derived from their evaluation for this purpose consisted of the total steel labor hours and the labor hours (or surface areas of steel components) for painting. The machinery and outfitting labor hours for the 40K and 95KDWT base vessels have been assumed constant, with the exception of those required for painting. Therefore, it has been assumed that the time lines for steel assembly and erection are proportional to the total steel labor hours, and the time linefor painting is proportional to the labor hours (or surface areas) required for painting. Labor hours for painting were varied in proportion to the surface areas, so that either quantity may be used to modify the time line.

As previously stated, the base construction schedule shown in Figure 14 shows key milestones in the building process, and since it was considered desirable to include these in all schedules, the following procedure was adopted to estimate the construction schedules for the structural alternatives:

- With reference to Figure 14, no change was made to the location of the milestone for the cmmencement of steel fabrication.
- The time line for steel assembly preceding keel laying was modified in proportion to the total steel labor hours, resulting in relocation of keel laying and all subsequent key milestones.
- The time lines for steel assembly and erection located between keel laying and launching were modified in proportion to the total steel labor hours. The time line for painting preceding launching was modified in proportion to the total painting labor hours.

Since these three construction processes overlap in this portion of the schedule, the changes in their corresponding time lines were then averaged to provide the accumulative effect upon the time required between keel laying and launching. Keel laying and all subsequent key milestones were then again relocated to suit.

- The time line for painting following launching was modified in proportion to the total painting labor hours, resulting in further relocation of the milestones for sea trials and ship delivery.

The resulting construction schedules for all of the 40K and 95KDWT structural alternatives are shown in Figures 17 and 18 respectively. For comparison purposes, the Far East schedule of 20.5 months has also been incmporated in these figures.

The labor hours and construction schedules shown in Figures 15 through 18 for baseline vessels" constructed in the Far East are considerably smaller than those for the various alternatives constructed in the U.S. and show the effect of increased automation, increased accurcy control and reduced design labor hours, as these were the only variables considered significant in differentiating the U.S. and Far East labor hours and schedules.

In the interest of testing this hypothesis, the automation, accuracy control, and design time were improved for alternatives 4010, 4090 and 40110, yielding alternatives 4010N, 4090N and 40110N. The improvements reflect the following:

- Floor and girder stiffeners are assumed automatically welded. Field welds of side shell, decks and longitudinal bulkhead are assumed automatically welded.
- Accuracy control improved by careful edge preparation and increased statistical measurements reducing rework from 10% to 2%.
- Design labor hours, due to standardization was reduced to 100,000 hours.

A comparison of the alternatives before and after these assumptions are shown in Figures 19 and 20 using the method of evaluations contained herein. They demonstrate that the improvements noted reduce the difference in labor hours between the Far Eastern Baseline and the U.S. constructed vessel in the order of 12%.

CONCLUSIONS

The physical characteristics, together with the estimated labor hours and construction schedules, provide a measure of producibility of the alternative structural concepts. The estimated labor hours for construction of the 40KDWT alternatives, shown in Figure 15, indicate that the labor hours for most of the alternatives are within 20,000 (about 3%) of the 712,813 hours estimated for the baseline alternative 4010. As an example, alternative 4070 shows the benefit (about 10,000 hours reduction) of using rolled sections (bulb plates) in lieu of built-up sections. The results show that the effect of the different structural elements used in the various alternatives is generally small. Exceptions to this trend include unidireuional alternative 40100 (+80,000 hours) and dished plate unidirectional alternatives 40120 (+150,000 hours) and 40121 (+40,000 hours). These results are perhaps surprising, since unidirectional designs incorporate significantly less structural pieces, but the increased labor hours for these vessels appears to be largely due to increased flame cutting/welding hours etc. necessitated by increased plating thickness. Also, the scantlings of dished plate unidirectional alternatives were maintained constant around the entire periphery of the midship section, which again incurs additional labor hours due to oversized Scantlings in some areas. More notable exceptions are alternative 40140, which shows the advantage of series production of the baseline vessel, assuming labor hours are halved, and alternative 40150, which shows the advantage of using standard designs for structural details, assuming the design labor hours are halved. Finally, the comparison in Figure 19 represents alternatives where the design labor hours have been halved, welding automation increased, and accuracy controlincreased reduce rework to 2%.

The estimated labor hours for construction of the 95KDWT alternatives, shown in Figure 16, indicate similar trends relative to the 958,082 hours estimated for the baseline alternative 9510 as exhibited by the 40KDWT alternatives. Labor hours for unidirectional altenative 95100 were not estimated, but dished plate alternatives 95120 and 95121 show about +100,000 hours and -10,000 hours relative to the baseline vessel 9510. This shows a somewhat improved level of producibility than that shown by the corresponding 40KDWT vessels.

Further to the increased plating thickness for unidirectional alternatives referred to above, this increase is due to the wider spacing of the longitudinal girders as compared with conventional longitudinal stiffeners. Some reduction in plate thickness is achieved in dished plate unidirectional designs by the adoption of curved plating, but the steel steel weight of both versions of the dished plate hull exceeds that of a corresponding conventional double hull design. The advantage of dished plating compared with fiat plating may be iliustrated by comparing the shell plating thickness for each case, utilizing dished plate alternative 40120 with 2.4M. girder spacing. A thickness of 25.4mm. was estimated for dished plating, but this increased to 45mm. for flat plating. The steel weight of one midship cargo tank length would then increase by 37.6%, and the estimated steel labor hours would increase by 45%.

The construcution schedules for the 40KDWT alternatives, shown in Figure 17, indicate that the schedules for most of the alternatives are equal to or slightly lower than that of the 29.1 months required for the baseline alternative 4010. Exceptions include 40100, 40120, 40140 and 40150, referred to in the preceding discussion of labor hours. It may be noted that the schedule for 40140 is only slightly grea!er than the 20.5 months required for construction in the Far

East, but of came a similar advantage for series production should be expected to apply there as well. The schedule for 40150 shows a reduction of about 3 months from the schedule for 4010.

Similar trends are exhibited by the construction schedules for the 95KDWT alternatives, shown in Figure 18. The schedule for the baseline alternative 9510 is 29.1 months, as for the 40KDWT baseline 4010.

The labor hours and construction schedule shown in Figures 15 through 18 for baseline vessels constructed in the Far East are considerably smaller than those for the alternative construced in the U.S. Figures 19 and 20 demonstrate how improved automation, accuracy control, and reduced design labor hours can reduce the labor hours significantly. This suggests that these areas are where the greatest gains may be possible to make U.S. shipyards more productive and more competitive on a world scale. It is likely that to maximize such improvements will rquire facilities enhancements to mimic Table II, which is beyond the scope of this study.

The differences between the design labor hours in Japan and the U.S. can only be explained by the existence of standard ship designs and design standards in Japan. It should also be noted that the absence of such standards incurs increased risk in time phased material procurement. These differences can also suggest a production labor force which rquires fewer drawings for construction,. which also suggests standardization.

ACKNOWLEDGEMENT

The material of this paper has been largely based on the results of a project [2] for the U.S. Ship Structure Committee with the input of a number of organizations and individuals. Messrs. Louis Chirillo and Roger Kline supported M. Rosenblatt & son, Inc. as consultants. The authors thanks Ms. Connie Frost for preparation of the manuscript.

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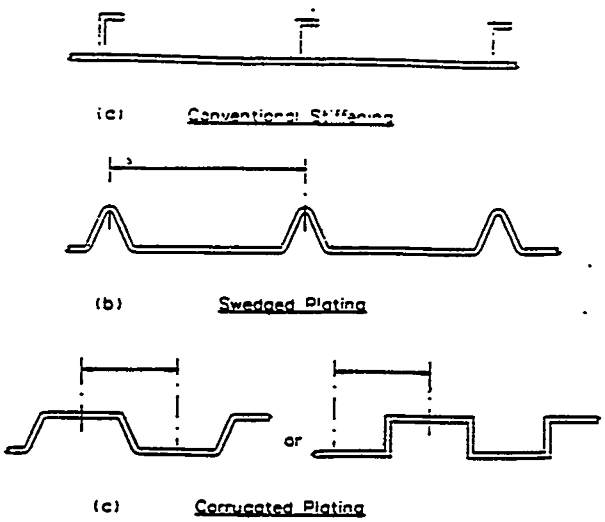


Figure 1
ALTERNATIVE METHODS FOR STIFFENING PLATING

Figure 2
STIFFENED ELEMENTS FORMED FROM ONE FRAME (OR STIFFENER) SPACE WIDTH OF PLATE WITH STIFFENER FORMED ON ONE SIDE.

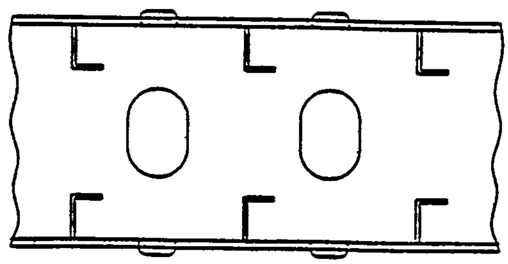


Figure 3
LUGGED AND SLOTTED STRUCTURE

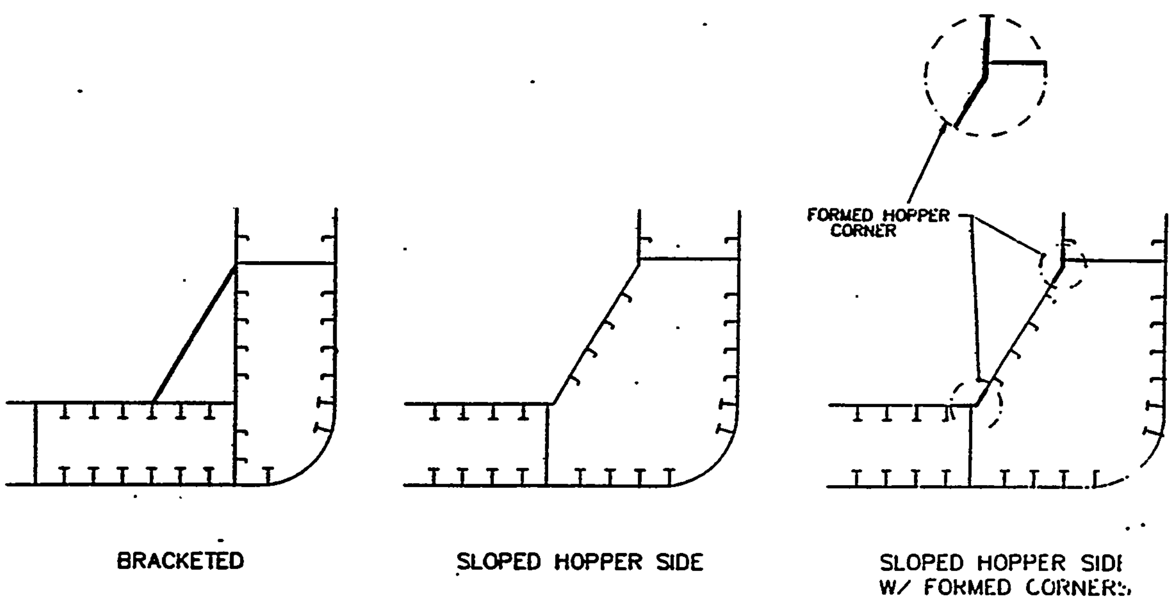


FIGURE 4 — TYPES OF LOWER HOPPER CORNERS

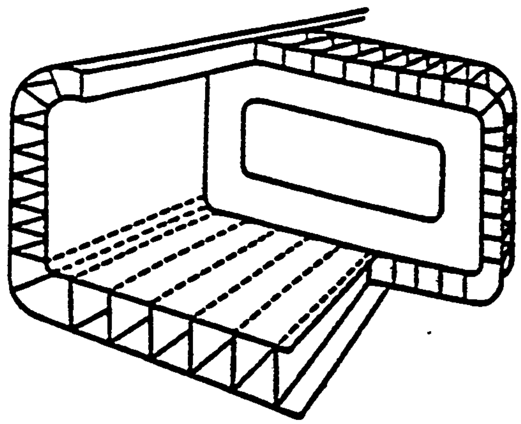


FIGURE 5

UNIDIRECTIONAL DOUBLE HULL

STRUCTURAL SYSTEM.

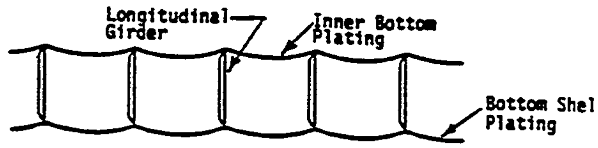


FIGURE 6

DISHED PLATE UNIDIRECTIONAL

DOUBLE HULL STRUCTURAL SYSTEM

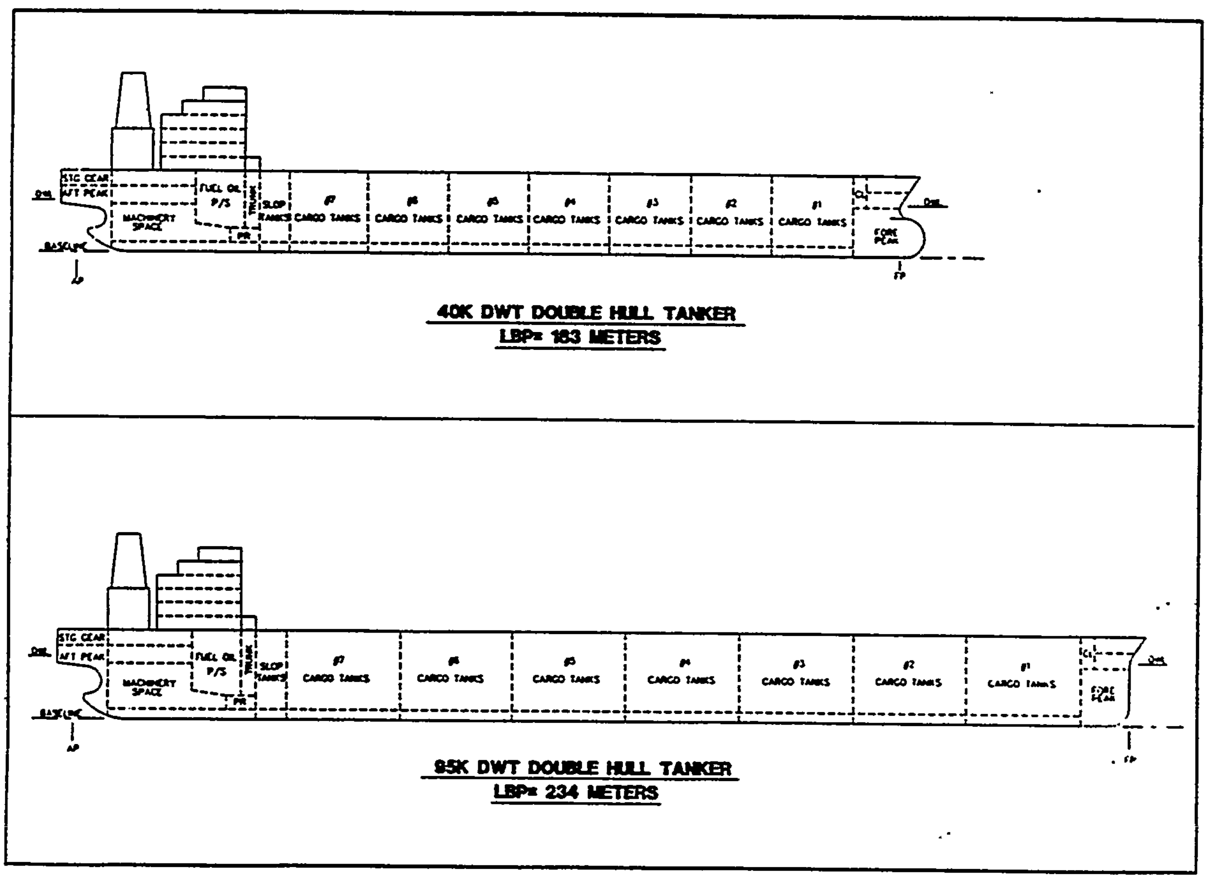


FIGURE 7- GENERAL ARRANGEMENTS

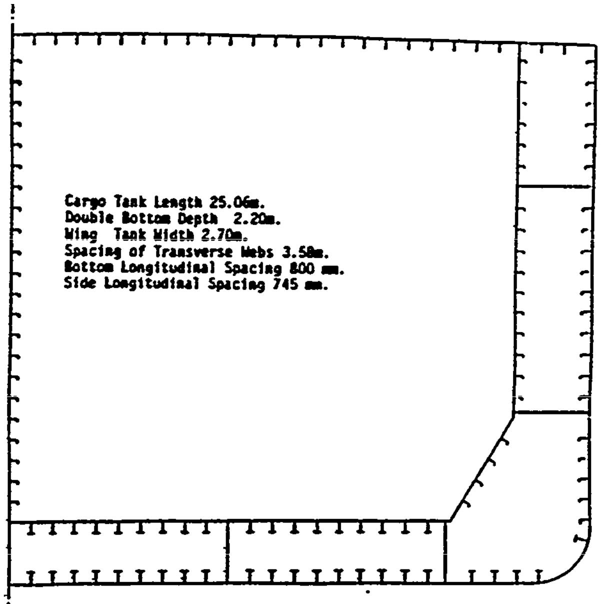


FIGURE 8

95KDWT BASELINE MIDSHIP SECTION

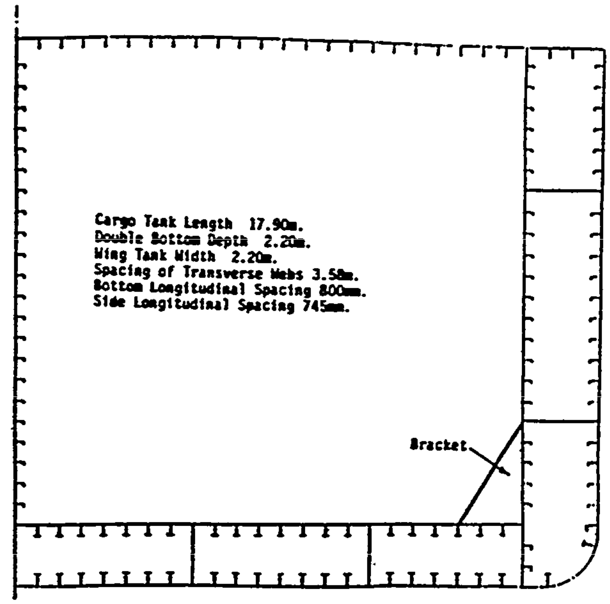
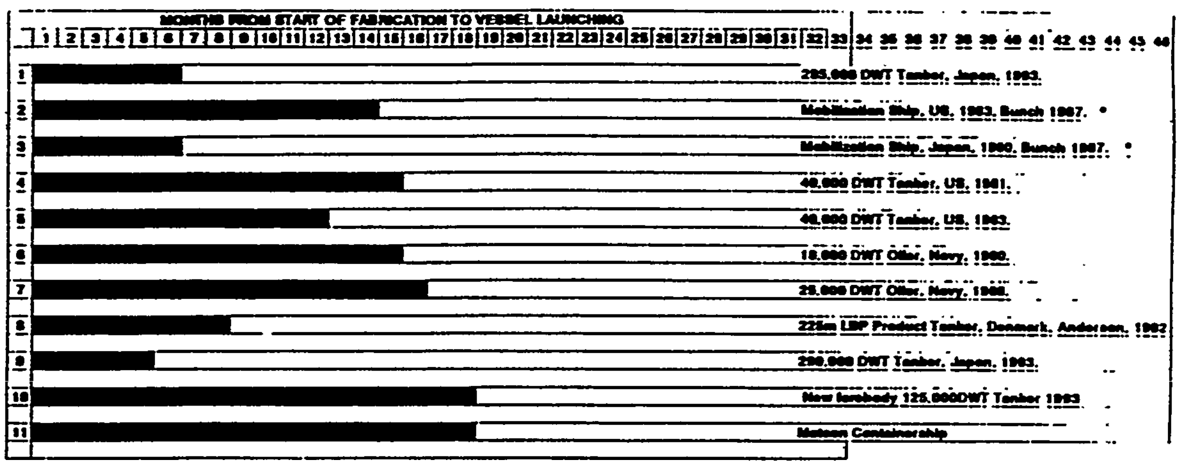


FIGURE 9

40KDWT BASELINE MIDSHIP SECTION



* Vessels not built

FIGURE 10

FABRICATION TO LAUNCHING TIME LINES

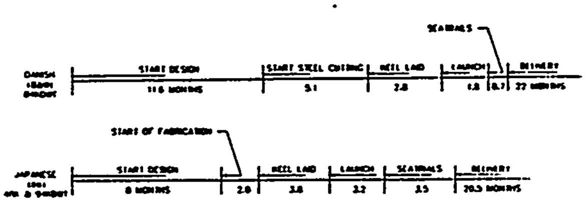


FIGURE 11

CONSTRUCTION SCHEDULE

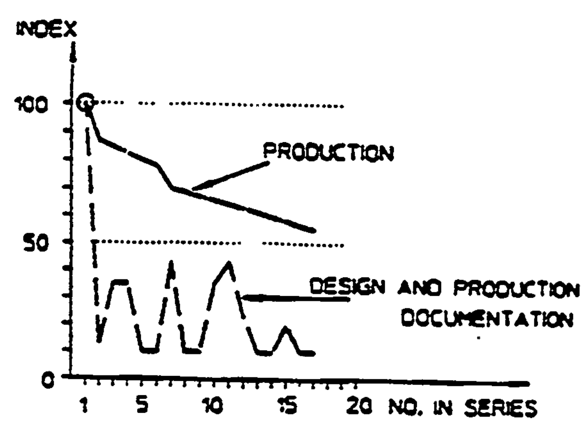


Figure 12
Learning Curve for Series Production, [B&W]

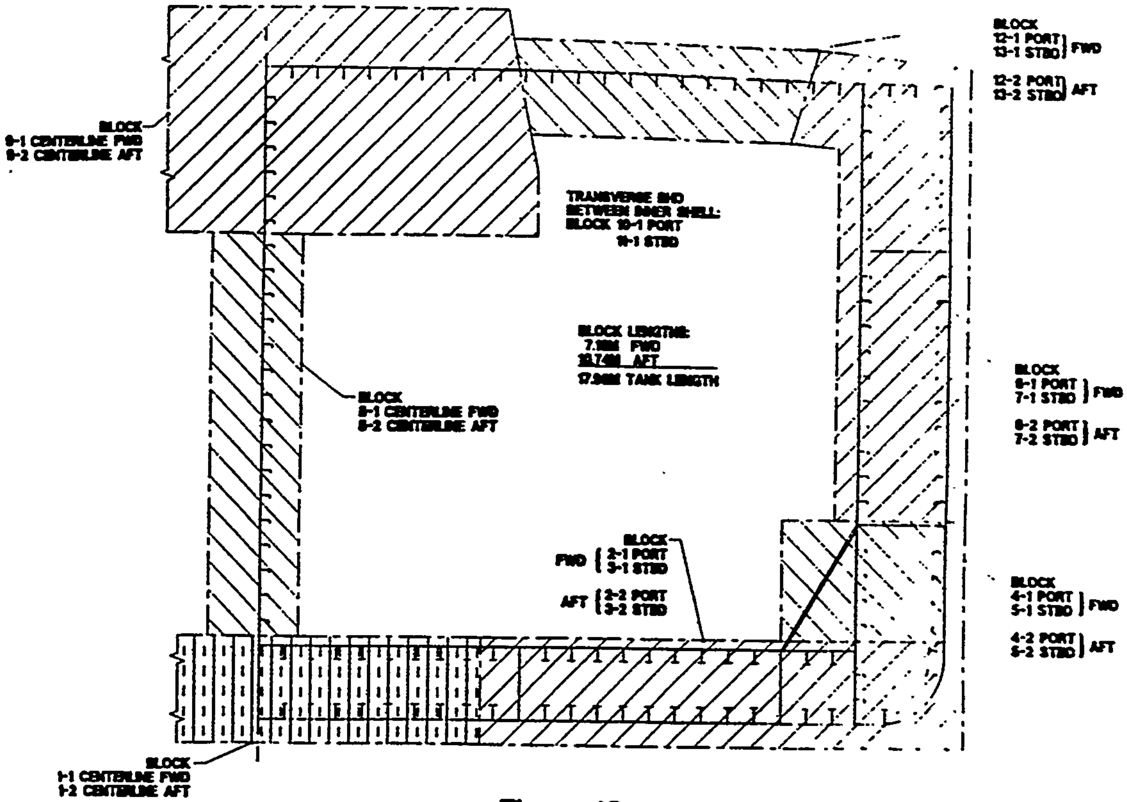


Figure 13

BLOCK BREAKDOWN FOR 40KDWT BASELINE

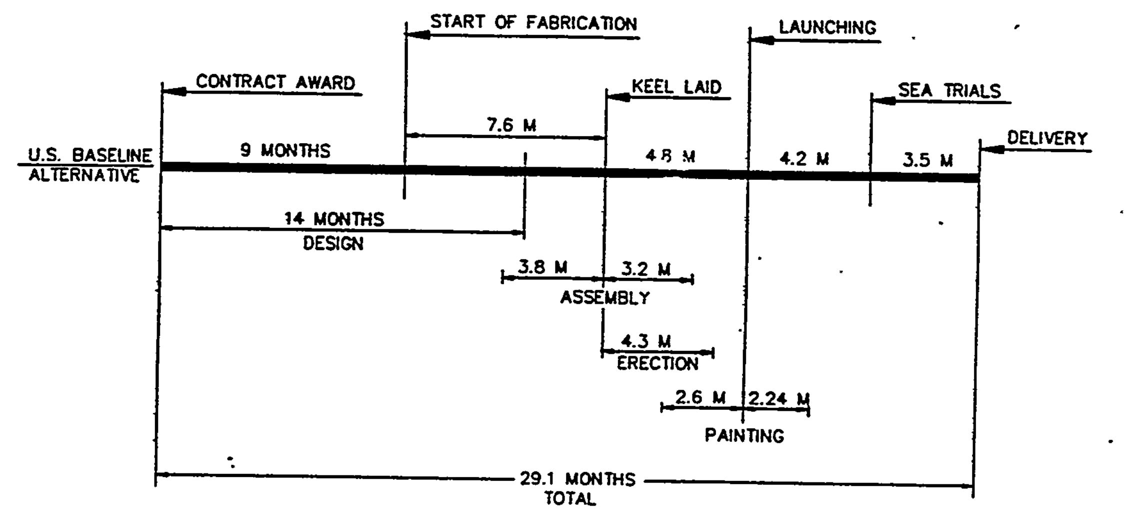


FIG. 14 - 1994 U.S. BASE TIME LINE SCHEDULE

FIGURE 15

ESTIMATED 40KDWT SHIP LABOR HOURS
1994 U.S. DESIGN AND CONSTRUCTION

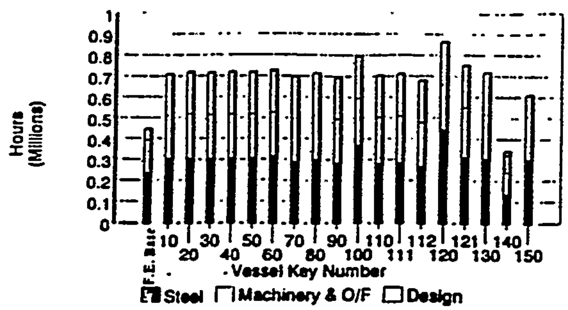


FIGURE 16

ESTIMATED 95KDWT SHIP LABOR HOURS
1994 U.S. DESIGN AND CONSTRUCTION

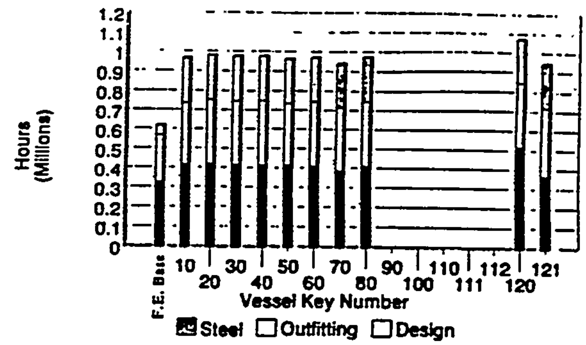


FIGURE 17

CONSTRUCTION SCHEDULE
40KDWT ALTERNATIVES

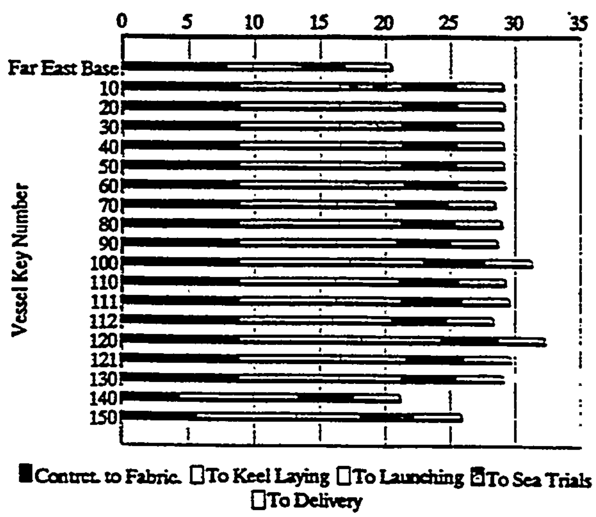


FIGURE 18

CONSTRUCTION SCHEDULE
95KDWT ALTERNATIVES

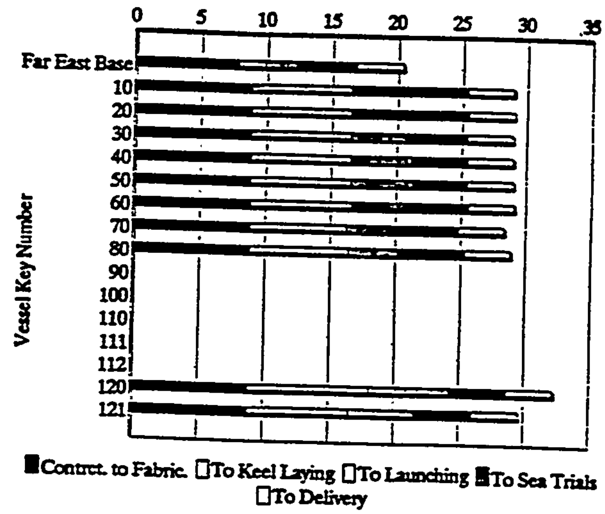


FIGURE 19

ESTIMATED 40KDWT SHIP LABOR HOURS
1994 U.S. DESIGN AND CONSTRUCTION

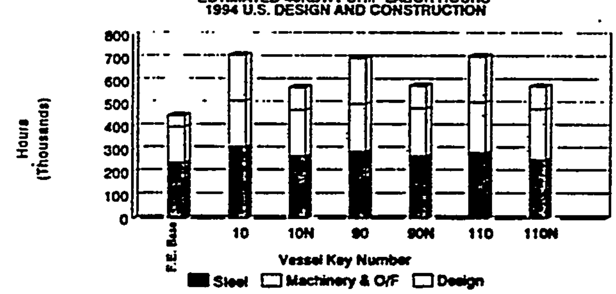
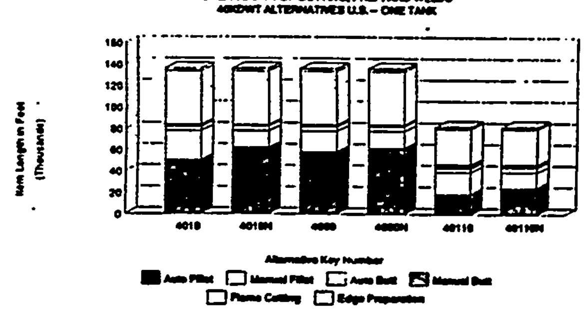


FIGURE 20

BREAK DOWN OF CUTTING, PREP. AND WELDS
40KDWT ALTERNATIVES U.S. – ONE TANK



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